On the refurbishment of the public building stock toward the nearly zero-energy target: two Italian case studies

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 101 (2016) 105 – 112

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

On the refurbishment of the public building stock toward the nearly zero-energy target: two Italian case studies

Vincenzo Corrado[a], Giovanni Murano[a,b], Simona Paduos[a,]*, Giovanni Riva[b]

[a]Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy
[b]Italian Thermotechnical Committee Energy and Environment (CTI), Via Scarlatti 29, Milano 20124, Italy

Abstract

The study presents some results of the on-going European Project, RePublic_ZEB, on the refurbishment of the public building stock towards nearly Zero Energy Building (nZEB). The work is focused on the application of the nZEB requirements to two existing public buildings representative of the 1960s in Northern Italy. Many packages of energy efficiency measures that comply with nZEB requirements are identified and evaluated. The aim is to promote energy efficient but also cost-effective solutions for the Italian building stock refurbishment. The results are presented in terms of “package of measures”, energy consumption, global costs, actualized pay-back period and CO_2 emission.

Peer-review under responsibility of the Scientific Committee of ATI 2016.

Keywords: nearly zero-energy building; public building stock; retrofit measures; cost-effectiveness; simplified models.

1. Introduction

Since the adoption of the European Directive 2010/31/EU [1] on the energy performance of buildings (EPBD recast) establishing the target of nearly Zero Energy Buildings (nZEB), several projects focused on this topic. ENTRANZE project (2012-2014) supported the policy makers by providing the required data, the analysis and the guidelines to achieve a fast and strong penetration of the nearly zero-energy target within the existing national building stocks through the connection of building experts from European research and academia to national

* Corresponding author. Tel.: +39-011-090-4549; fax: +39-011-090-6329.
E-mail address: simona.paduos@polito.it

Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.014

decision makers and key stakeholders [2]. SOUTHZEB (2014-2015) still focused on nZEBs but in the traditional villages and areas of tight architecture regulations in Southern EU [3]. ZEBRA2020 is an ongoing EU project started in 2014 with the aim to create an observatory for nZEBs able to derive recommendations and strategies for EU policy makers, energy agencies and stakeholders to accelerate the nZEB market [4].

In this context, RePublic_ZEB project [5], started in 2014, focuses in the refurbishment of the public building stock towards nZEB in the countries of the South-East of Europe. The main objective is to support the participant countries to develop and promote on the market a set of concrete technical solutions for the refurbishment of the public building stock towards the nearly zero-energy target. To achieve this goal, an assessment of the current public building stock and the definition of reference buildings are provided. The main outcomes of the project are a set of cost optimal and low-risk packages of measures suitable for the refurbishment of the public buildings towards nZEB, which will be included in guidelines, and the promotion of activities addressed to national and regional authorities as well as to construction industry, housing organizations, owners of large building stock and developers. Some of the preliminary results of the applied methodology for identifying the cost-optimal levels of the energy performance requirements are shown in [6]; this work presents the Italian contribution.

Nomenclature

A	area	[m^2]
C	cost	[€]
COP	coefficient of performance	[-]
DHW	domestic hot water	[-]
EER	energy efficiency ratio	[-]
E	energy	[kWh]
EP	energy performance	[kWh m^{-2}]
F_D	daylight factor	[-]
F_C	occupancy factor	[-]
g	global solar energy transmittance	[-]
GC	global cost	[€]
PBP_{act}	actualized pay-back period	[year]
PN	lighting power density	[W m^{-2}]
RER	renewable energy ratio	[%]
U	thermal transmittance	[W m^{-2}K^{-1}]
V	volume	[m^3]
W_p	peak power	[kW]
Δ	differential	[-]
τ_s	solar transmittance coefficient	[-]
η	energy efficiency	[-]

Subscripts

C	cooling	H	heating
coll	collectors	n	net
ctr	control	nren	non-renewable
d	distribution	op	opaque wall
e	emission	P	primary
env	envelope	r	roof
f	floor	ren	renewable
g	gross	tot	total
gl	global	ve	ventilation
gl,n	glass, normal incidence	w	window
gn	generation	W	domestic hot water

2. Method

2.1. The energy performance assessment

As specified in ISO/DIS 52000-1:2015 [7], the EP is expressed as the building global primary energy demand ($E_{P,gl}$) divided by the conditioned area. The global primary energy refers to all the EPBD energy services (heating, cooling, DHW, ventilation, lighting) and it is calculated according to the above standard. The EP can either include only non-renewable energy (EP_{nren}), or include both non-renewable and renewable energy (EP_{tot}):

$$EP_{tot} = EP_{nren} + EP_{ren} \tag{1}$$

The Renewable Energy Ratio (RER) is the ratio of the renewable primary energy to the total primary energy:

$$RER = \frac{EP_{ren}}{EP_{tot}} \tag{2}$$

The energy performance is fully described by a couple of indicators: EP_{tot} and EP_{nren}, or alternatively, EP_{tot} and RER. The first step is the calculation of the energy need for heating and cooling by means of the quasi-steady state numerical model of the Italian technical specification UNI/TS 11300-1, which implements the international standard EN ISO 13790:2008 [8]. As well, the delivered energy is calculated by means of the Italian technical specification UNI/TS 11300 series [9], which implements the European standards EN 15316 series [10] and EN 15243:2007 [11]. The energy demand for lighting is calculated by means of the EN 15193:2007 standard [12].

2.2. The global cost calculation

The Commission Delegated Regulation No. 244/2012 [13] requires the evaluation of the cost optimal level both at a macroeconomic and at a financial level. Concerning the financial level calculation, the methodology is based on the overall costs, considering the initial investment, the sum of the annual costs for each year (energy, maintenance, operation and any additional costs), the extraordinary replacement of systems and components, the final value, and the costs of disposal, as appropriate. All costs are actualized to the starting year. In the macroeconomic approach, the costs corresponding to the CO_2 emissions are also considered.

For the RePublic_ZEB purposes, the financial perspective calculation is applied, without considering subsidies. The financing framework methodology is based on the net present value (global costs, GC) calculation, carried out according to standard EN 15459:2007 [14], which provides a method for considering the economic aspects related to the application of heating systems and other technical systems that affect the energy consumption of the building.

2.3. The cost optimal approach

In the RePublic_ZEB context, a tool to calculate the optimal levels of minimum energy performance requirements towards nZEB was developed, which is in accordance with [13] and the accompanying Guidelines [15]. The tool is based on the Italian cost optimal methodology framework, but it was modified in such a way as to consider the partners' assumptions. The energy cost optimization procedure is based on a sequential search-optimization technique [16]. The method considers, for each energy efficiency measure, a discrete number of options (e.g. different levels of thermal insulation), described by relevant performance parameters (e.g. thermal transmittance) and by specific costs. Different packages of energy efficiency measures are applied and compared: each package is a set of energy efficiency options, one for each measure. Among all the considered packages of measures, the optimization process allows to identify those characterized by the lowest global cost within the calculation period.

2.4. The nZEB definition

A common definition of the nearly zero-energy target that is in line with the EU Directive [1], has been agreed within the RePublic_ZEB consortium. A building is considered as nZEB when the following requirements are met: the EP is lower than the cost optimal level (the nZEB is more energy efficient than the cost optimal building); the differential Global Cost (ΔGC) with reference to the building before the refurbishment is negative (nZEB is cost effective); the national minimum energy performance requirements for nZEBs are fulfilled. Thus, the nZEBs should have a primary energy consumption lower than the cost optimal range, and the global cost in between the cost optimal cases and the current reference building.

As regards the renewable energy production, a minimum value of the Renewable Energy Ratio (RER) is specified at country level; for public buildings in Italy, $RER_W > 55\%$, $RER_{H+C+W} > 55\%$ [17].

3. Calculation

3.1. The case studies

The present work analyzes an office and a school chosen among the Italian case studies of the RePublic_ZEB project. Both are real buildings placed in Torino (2617 HDD), representative of the 1960s public building stock. The main characteristics are reported in Tab.1.

Table 1. Main parameters of the office and school reference buildings.

Geometrical data			Construction data			System data (description and mean seasonal efficiency)	
	Office	School		Office	School	Office	School
V_g	20638	39760	U_{op}	0.68	2.07	Radiators and fan-coils ($\eta_{H,e}$ 0.87)	Radiators and fan-coils ($\eta_{H,e}$ 0.91)
$A_{f,n}$	4521	8598	U_w	2.87	4.08	Room and climatic temperature control ($\eta_{H,ctr}$ 0.86)	Climatic temperature control ($\eta_{H,ctr}$ 0.83)
A_{env}/V_g	0.23	0.32	$g_{gl,n}$	0.75	0.75	Central distribution, horizontal pipes ($\eta_{H,d}$ 0.96)	Central distribution, horizontal pipes ($\eta_{H,d}$ 0.90)
A_w	628	2436	U_f	0.94	1.32	2 natural gas generators ($\eta_{H,gn}$ 0.87)	3 natural gas generators ($\eta_{H,gn}$ 0.77)
No. floors	7(+2)	3(+1)	U_r	1.69	1.43	Electrical storage water heater ($\eta_{W,gn}$ 0.80)	Natural gas generator ($\eta_{W,gn}$ 0.86)
						Indoor units split systems ($\eta_{C,e}$ 0.97)	No cooling system

3.2. The energy efficiency measures

In the retrofit process of the buildings a whole renovation is considered; the energy efficiency measures (EEMs) concern both the fabric and the technical systems (Tab.2). The EEMs from 1 to 6 consider the envelope (e.g. exterior insulation, windows replacement, solar shading devices); the EEMs from 7 to 11 involve the technical systems for space heating/cooling and/or DHW (e.g. replacement of the heat generator) and take into account technologies like condensing boiler, biomass generator, district heating, air-to-air and air-to-water heat pumps. The EEMs 12 and 13 concern the energy production from renewables (i.e. solar collectors and PV panels), while EEM 14 the heat recovery ventilation system. Finally, an advanced control for space heating (EEM 15) and the lighting system replacement are considered (EEM 16 and 17).

There are up to five energy efficiency options (EEOs) for each EEM, representing different levels of performance. For each EEO the specific cost is estimated. Tab.2 summarizes the EEOs thermal parameters values and the referred costs for the considered reference buildings. The costs exclude 23% VAT but include extra-costs for lathing and technical systems adjustment.

Table 2. Energy efficiency measures (EEMs), and related options (EEOs) and costs.

No.	EEM	Parameter	Office EEO 1	2	3	4	5	School EEO 1	2	3	4	5
1	External wall thermal insulation	U_{op}	0.27	0.23	0.21			0.26	0.24	0.20		
		C/A	44.21	46.55	48.95			48.95	53.75	74.85		
2	Wall vs unconditioned spaces	$U_{op,u}$	0.30	0.25	0.21	0.19		0.29	0.28	0.25	0.24	
		C/A	31.13	32.39	42.40	44.92		29.85	34.85	31.13	37.35	
3	Roof/last floor thermal insulation	U_r	0.24	0.21	0.19			0.25	0.23	0.22	0.2	
		C/A	39.28	44.01	49.13			46.03	39.28	52.69	44.01	
4	Ground/first floor thermal insulation	U_f										
		C/A										
5	Window thermal insulation	U_w	1.49	1.35	1.16	0.91		1.4	1.16	0.92	0.86	
		C/A	387.3	308.0	300.2	399.6		140.7	163.7	189.2	200.7	
6	Solar shading system	τ_s	0.4	0.35				0.4				
		C/A	113	95				113				
7	Chiller	EER	5	6								
		C	66934	75880								
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	1.1	0.88	3.7							
		C	51050	30276	206818							
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	2.6									
		C	15082									
10	Combined generator for heating, DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP	1.1	0.88	3.9			1.1	0.9	0.88	4.3	
		C	59296	30276	215059			59296	133054	30276	264522	
11	Heat pump for heating, DHW, cooling, and appropriate emission system	COP	4.3									
		EER	3.1									
		C	215059									
12	Thermal solar system	A_{coll}						10	16	5	18	
		C						6920	10188	6789	20362	
13	PV system	W_p	27	47	70	85		20	40	60	150	
		C	12221	26607	45401	82452		19835	54667	121682	225000	
14	Heat recovery ventilation system	η_{ve}	0.7					0.7				
		C	30740					35511				
15	Heating control system	η_{ctr}	0.995					0.995				
		C	31526					43726				
16	Lighting system	PN	10.85	10.85	6.09	6.09	6.09	7.91	7.91	4.34	4.34	4.34
17	Lighting control system	F_D (F_C)	1(0.9)	0.9 (0.9)	1(0.9)	0.9(1)	0.9 (0.9)	1(0.9)	0.9 (0.9)	1(0.9)	0.9(1)	0.9 (0.9)
		C	19794	31236	68712	68712	80154	26715	39175	120143	120143	132603

3.3. Assumptions

The EP is expressed in terms of non-renewable primary energy (EP_{nren}) and the RER ratio. The primary energy factors are assumed according to the Italian regulation [17]. The electricity from PV panels is considered as a reduction of the monthly electrical energy demand; the exported electrical energy is not considered.

The following assumptions are used for the GC calculation: period of 30 years; 3% real interest rate; electricity and natural gas costs from the National Authority for Electricity and Natural Gas (AEEG); biomass cost from market surveys; energy trend scenarios developed with the PRIMES model according to [18]; annual maintenance costs variable from 0% to 4% of the investment cost depending on the technology; technical lifespan of building elements fixed at 20 years, of systems variable from 15 to 20 years.

4. Results

Concerning the optimal retrofit of the office building (Tab.3), the following measures are considered: the opaque components thermal insulation, the PV panels and the heat recovery ventilation system installation, the heating system control and lighting system replacements. The proposed nZEB solutions increase the thermal insulation and add the movable shading system. Moreover, in order to achieve the RER goal, different technical systems have been considered: centralized heat pump for heating, cooling and DHW (nZEB1); centralized heat pump for heating and DHW (nZEB2); heat recovery ventilation and centralized heat pump (nZEB3). In all the solutions, the climatic plus ambient heating control system and the PV panels have been considered, while the lighting system has been equipped with T5 lamps and daylight control.

The results in Tab.4 show that the optimal retrofit of the school considers the following EEMs: all the envelope components thermal insulation; the generator replacement with district heating; the PV panels and the heat recovery ventilation system installation; the lamps and lighting control replacement. In order to achieve the nZEB goal, the proposed solutions reduce the energy need by adding a higher thermal insulation and a movable shading system. Moreover, different technical systems have been considered: biomass boiler (nZEB1); centralized heat pump for heating and DHW, and PV panels (nZEB2 and 3). In all the nZEB solutions, the climatic plus ambient heating control, the heat recovery ventilation, and the lighting system (lamps and control) have been renovated.

Table 3. Cost-optimal and nZEB packages of measures of the office building.

No.	Energy Efficiency Measure EEM	Parameter	Before refurbishment	Cost optimal	nZEB1	nZEB2	nZEB3
1	External wall thermal insulation	U_{op}	0.94	0.23	0.27	0.27	0.21
2	Wall vs unconditioned thermal insulation	$U_{op,u}$	1.72	0.25	0.25	0.25	0.21
3	Roof/last floor thermal insulation	U_r	1.69	0.24	0.24	0.24	0.19
4	Ground/first floor thermal insulation	U_f	0.96				
5	Window thermal insulation	U_w	2.87		1.49	1.49	
6	Solar shading system	τ_s			0.4	0.4	0.35
7	Chiller	EER	3.0				
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	0.87				
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	0.80				
10	Combined generator for heating and DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP				3.9	3.9
11	Heat pump for heating, DHW and cooling, and appropriate emission system	COP EER			4.3 3.1		
12	Thermal solar system	A_{coll}					
13	PV system	W_p		70	70	85	70
14	Heat recovery ventilation system	η_{ve}		0.7			0.7
15	Heating control system	η_{ctr}	0.86	0.995	0.995	0.995	0.995
16	Lighting system	PN	12.0	10.85	10.85	10.85	10.85
17	Lighting control system	F_D (F_C)	1.0(1.0)	0.9(0.9)	0.9(0.9)	0.9(0.9)	0.9(0.9)

Table 4. Cost-optimal and nZEB packages of measures of the school.

No.	Energy Efficiency Measure EEM	Parameter	Before refurbishment	Cost optimal	nZEB1	nZEB2	nZEB3
1	External wall thermal insulation	U_{op}	2.10	0.26	0.26	0.26	0.26
2	Wall vs unconditioned thermal insulation	$U_{op,u}$	0.85	0.25	0.28	0.28	0.29
3	Roof/last floor thermal insulation	U_r	1.43	0.23	0.23	0.23	0.23
4	Ground/first floor thermal insulation	U_f	1.32				
5	Window thermal insulation	U_w	4.10	1.40	1.16	1.16	0.92
6	Solar shading system	τ_s			0.4	0.4	
7	Chiller	EER					
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	0.91				
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	0.86				
10	Combined generator for heating and DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP		0.88	0.90	4.3	4.3
11	Heat pump for heating, DHW and cooling, and appropriate emission system	COP EER					
12	Thermal solar system	A_{coll}					
13	PV system	W_p		150		150	150
14	Heat recovery ventilation system	η_{ve}		0.70	0.70	0.70	0.70
15	Heating control system	η_{ctr}	0.83	0.995	0.995	0.995	0.995
16	Lighting system	PN	9.00	7.91	4.34	4.34	4.34
17	Lighting control system	F_D (F_C)	1.0(1.0)	0.9(0.9)	0.9(0.9)	0.9(0.9)	0.9(0.9)

In Fig.1 all the solutions are shown, for the office (a) and the school (b) respectively. As regards the office, the nZEB solution that records the lowest ΔGC is the No. 3, that is characterized by a 110 € m^{-2} global cost lower than the current state of the reference building, and a total energy performance of 88 kWh m^{-2}, of which only 44 kWh m^{-2} are non-renewable. As regards the school, the nZEB solution that records the lowest ΔGC is the No. 3, that is similar to the cost optimal solution in terms of costs and EP; it is characterized by a 620 € m^{-2} global cost lower than the reference building in its current state, and a total energy performance of 112 kWh m^{-2}, of which 53 kWh m^{-2} are non-renewable.

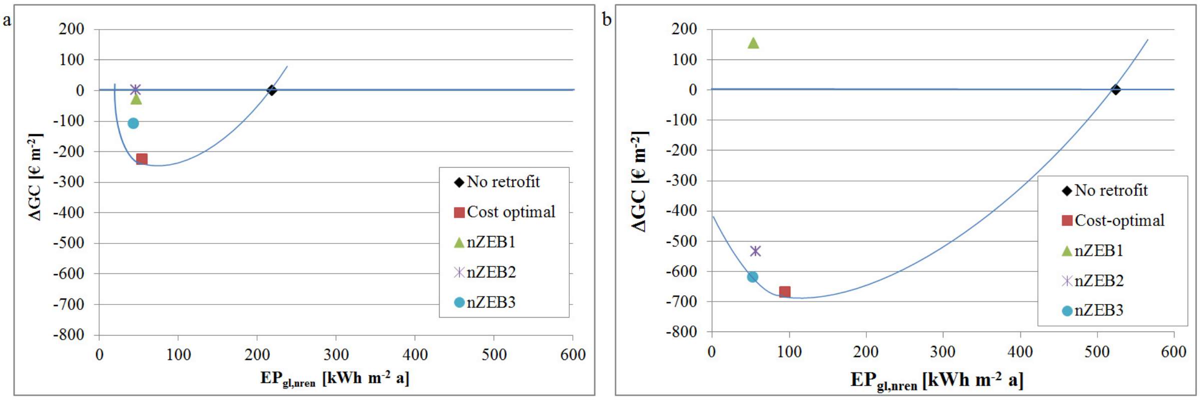

Fig. 1. ΔGC and referred EP$_{gl,nren}$: current state of the building, cost-optimal, nZEB. Office (a); school (b).

The PBP$_{act}$ associated to each case is shown in Fig.2 for the office (a) and the school (b), while Fig.3 shows the CO_2 emission. The PBP$_{act}$ referred to all the solutions is lower than 30 years, namely the duration of the calculation time, except for the nZEB1 solution of the school. Fig.3 puts in evidence the deep reduction of the CO_2 emission.

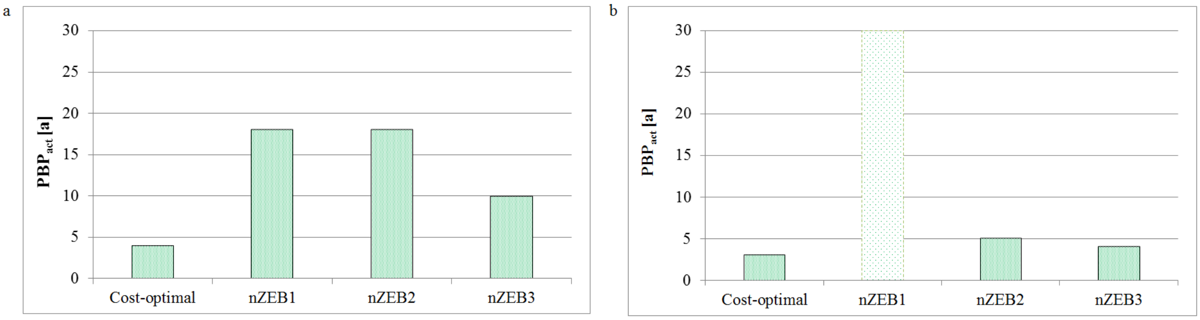

Fig. 2. PBP$_{act}$: cost optimal and nZEBs solutions. Office (a); school (b).

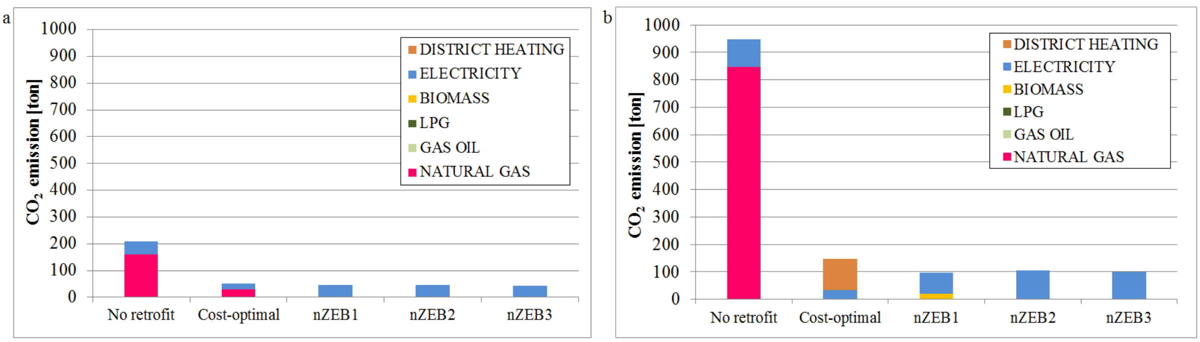

Fig. 3. CO_2 emission: current state of the building, cost optimal, nZEBs. Office (a); school (b).

5. Conclusion

The work presents some results of the ongoing EU project RePublic_ZEB on the refurbishment of the public building stock towards the nearly zero-energy target. The paper shows the approach and the common methodology adopted in the project for the assessment of retrofit measures suitable to reach nZEBs. This approach is implemented into a tool available to all the partners, as to investigate cost-effective as well as high EP retrofit solutions.

The results of the application of the tool to two Italian reference buildings show that it is feasible to achieve the nearly-zero energy target. For both the considered reference buildings, the EP_{nren} associated to the nZEB solutions is lower than 100 kWh m^{-2}, while the retrofit cost effectiveness increases for buildings characterized by a very low energy performance at the current state, as the considered school: in similar cases the estimated global cost can reach values of about 600 € m^{-2} lower than the building before the retrofit. Low values of the PBP_{act} strengthen the cost effectiveness of the retrofit, however the calculation considers a continuous use of the building over the heating season. Finally, the heat pump combined with the PV system prevail among the EEMs: this technical solution seems to be the most cost-effective, energy performant, and suitable to reach the RER Italian requirements.

Acknowledgements

This work is based on the IEE Project RePublic_ZEB, financed by the European Commission through grant agreement no. IEE/13/886/SI2.674899.

References

[1] European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 18 June 2010.
[2] ENTRANZE project. www.entranze.eu.
[3] SOUTHZEB project. www.southzeb.eu.
[4] ZEBRA2020 project. www.zebra2020.eu.
[5] RePublic_ZEB project. www.republiczeb.org.
[6] Aelenei L, Paduos S, Petran H, Tarrés J, Ferreira A, Corrado V, Camelo S, Polychroni E, Sfakianaki K, Gonçalves H, Salom J, Riva G, Murano G. Implementing Cost-optimal Methodology in Existing Public Buildings. Energy Procedia 2015;78:2022-2027.
[7] International Organization for Standardization (ISO). ISO/DIS 52000-1:2015. Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures.
[8] European Committee for Standardization (CEN). EN ISO 13790:2008. Energy performance of buildings - Calculation of energy use for space heating and cooling; 2008.
[9] Italian Organisation for Stardardisation (UNI). UNI/TS 11300 (series). Energy performance of buildings; 2010-2016.
[10] European Committee for Standardization (CEN). EN 15316 (series). Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies; 2007-2011.
[11] European Committee for Standardization (CEN). EN 15243:2007. Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems; 2007.
[12] European Committee for Standardization (CEN). EN 15193:2007. Energy performance of buildings - Energy requirements for lighting; 2007.
[13] European Union. Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, 21 March 2012.
[14] European Committee for Standardization (CEN). EN 15459:2007. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings; 2007.
[15] European Union. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, 19 April 2012.
[16] Corrado V, Ballarini I, Paduos S. Assessment of cost-optimal energy performance requirements for the Italian residential building stock. Energy Procedia 2014;45:443–452.
[17] Italian Republic. Decree of the Italian Ministry of Economic Development 26 June 2015 "Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici". Official Journal of the Italian Republic, 15 July 2015.
[18] European Commission, Commission staff working document - Energy prices and costs report accompanying the document communication from the commission to the European parliament, the council, and the European economic and social committee and the committee of the regions. Energy prices and costs in Europe2014; Brussels, 2014.